BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 05075

SUBJECT: Discussion of Factors Influencing Cost of Servicing Astronomy Satellites - Case 105-3

DATE: May 21, 1969

FROM: D. Macchia

ABSTRACT

Information requirements and assumptions necessary to estimate the costs of servicing an astronomy satellite are outlined. Factors influencing servicing frequency, satellite design requirements, potential servicing hardware, servicing modes, programmatic issues, astronomy program cost elements, and possible cost models are among the topics discussed.

It is noted that estimates of servicing cost require the establishment of concurrent NASA programs, available logsitics systems and their operating costs, satellite servicing requirements, feasibility of different servicing modes, and a costing methodology.

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MEMORANDUM FOR FILE

Introduction

This memorandum discusses material related to a frequent question--What is the cost of servicing an astronomy satellite? The particular satellite is a complex, expensive telescope of the late 1970's time period such as an advanced OAO or ASTRA. These telescopes are currently envisioned to operate unmanned and unattached to any space station.

It would be desirable to improve telescope lifetime and experiment flexibility. Of obvious interest then, is what kind of servicing is required and feasible, and can servicing be accomplished at modest cost? Considerable information and numerous assumptions on servicing frequency and modes, hardware requirements, concurrent NASA programs, and cost modeling are necessary to answer this question. Much of the required information does not exist and many critical assumptions remain to be supplied by either NASA or the astronomers. Therefore, this paper only discusses information requirements and points out various servicing and costing options.

Factors Influencing Servicing Frequency

Servicing frequency is determined by several factors which are influenced by the telescope design, the performance requirements, or the manner in which the telescope is operated. This frequency can only be estimated for a particular telescope under an assumed mode of operation. Servicing frequency would actually be weighed against the cost of a servicing operation. A discussion of the variables affecting frequency follows.

1. Regular Servicing Requirements

Film change and resupply of propellants or other expendables would occur at regular or preplanned intervals. Whether or not these operations are performed and their frequency depends on telescope design. For example, an electronic imaging system could eliminate film changing operations.

2. Repair and Maintenance

Failures or degradation of satellite subsystems, experiments and optics will necessitate servicing. It is possible to compute a failure rate but it is not clear that such a computation has any meaning for a late 1970's type satellite. Such computations are based on incompletely understood failure mechanisms and historical data which is not applicable to future satellites. Nevertheless estimates of this nature will continually be made.

A recent study* has noted that between now and 1975 satellite failure rates will be reduced because of

- component and materials improvements,
- improved design techniques,
- conversions from discrete parts to microelectronics,
- component burn-in before installation, and
- on-orbit environmental K factors** less than 1.

And the following failure rate reductions are estimated:

- electronic assemblies - 90%
- electro-mechanical assemblies - 50%
- solar cells, sensors, transducers, and similar parts - 80%
- most mechanical assemblies - 40%
- active thermal control systems (fluid) - none.

These failure rate reductions were applied to a free flying solar or stellar telescope (see Figure 1) that would be serviced by a space station. Figure 2 summarizes the study results. The mission length of 18 months indicates solar and stellar telescope failures occurring approximately every 2 1/2 and 1 1/2 months respectively.

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*"Advanced Astronomy Missions Concept Study," Task 416-0.1A, NAS 8-24000, Martin-Marietta Corp., Final Review Presentation, January 31, 1969.

**Ground based data is multiplied by this factor to account for the severity of the new operating environment.

3. Performance Factors

Servicing operations, possibly at regular intervals, may be planned for experiment instrument change or calibration. Such requirements are uncertain, however. For example, an automated turret with several instruments could dispense with manned experiment changing. Regarding experiment calibration, it is not clear that manned servicing is practical.

Change of experiment instruments may also be required because of experiment obsolescence or installation of special purpose instruments. In a long life telescope, obsolescence can occur as a result of new instrument designs or techniques which permit more efficient data gathering or higher quality data. It is also possible that an instrument has simply completed its planned data acquisition.

The frequency of changing instruments for performance reasons, then, is dependent on telescope design and on the pre-planned manner of telescope operation.

<u>Satellite Servicing Design Requirements</u>

Servicing imposes several design requirements on an astronomy satellite (or any other satellite). These requirements will increase satellite cost over that of an unserviceable satellite Generally speaking it will be necessary to have:

- checkout and telemetry systems to identify and transmit failure data,
- a spares inventory at the service base,
- an emergency attitude control system,
- rendezvous and docking systems,
- accessible components (by EVA or IVA),
- replaceable expendables, and possibly
- a working volume to enclose serviceable experiments and compoments.

More specific requirements need more definition of the particular satellite to be serviced. Such things as the desired lifetime, flexibility or performance, and cost constraints all enter into decisions as to which of or to what degree these requirements are incorporated. It is noted that the kind of repair or modification practical will not be evident until the detail design phase of satellite development. Some comments on these requirements follow.

Several questions are immediately obvious regarding checkout and telemetry systems. How much diagnosis is possible at the satellite or via telemetry to the ground? Is it necessary to return a telescope to a major service base on the ground or in space? Thus it is not clear whether checkout systems will be located on a telescope, service vehicle, or space station. Similarly, it is necessary to establish what components should be spared and where these spares would be stored.

An emergency attitude control system is important for obvious reasons, particularly since a number of past satellite failures have occurred in this system (i.e., gyros, horizon sensors, propulsion components, and circuitry). In addition to attitude stabilization, actual attachment to a satellite requires rendezvous and docking systems such as antennas, transponders, and docking structure.

Accessibility to spacecraft components implies doors, handholds, modular units, working spaces, etc. Because of volume and weight penalties it may not be practical to provide accessibility to all components. This would tend to limit repair perations at the satellite location and require some degree of disassembly at the service base. The real limitations will not be uncovered until detail satellite design and development.* Along with accessibility requirements, all expendables (i.e., propellant, batteries, etc.) should be replenishable.

Another possible important requirement would be a working volume for servicing. This volume could be on a space station, an attached spacecraft, or on the telescope itself. These possibilities are indicated schematically in Figure 3. As can be seen, several levels of complexity are possible, each with their own associated costs. Which option is selected depends on the time and degree of manual dexterity required for servicing in addition to consideration of cost. The first option provides a hangar in a space station. This minimizes telescope servicing modifications but has great impact on the space station configuration, especially for a large telescope. The second option is essentially an AAP ATM mode. All servicing would be by EVA. Concepts requiring EVA servicing should not be discarded since advanced space suit designs of the 1970's may allow much safer, more mobil operations. The third option encloses part (or all) of a telescope in a working volume which can be docked to a space station or service vehicle. To minimize complexity this volume should be pressurized by the servicing vehicle rather than be autonomous.

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*For example, Itek studied the possibility of maintenance of the experiments portion of the Advanced Princeton Satellite concept (by Perkin-Elmer and Grumman). Refer to "Study of Telescope Maintenance and Updating in Orbit," Itek, May 27, 1968.

Potential Hardware Suitable for Servicing

For the late 1970's time period several manned systems may be available for servicing. Current planning is centered on a long term, multi-man, multi-disciplinary space station in low earth orbit. This station could permit servicing a telescope in a nearby or identical orbit. (Transportation to the telescope or space station would be provided by the station logistic system or propulsion systems on the telescope.)

Telescope orbits distant from a space station, e.g., in a different orbit plane, would probably be more economically serviced directly from earth with some type of logistics system. It is worth noting that existence of this logistics system is closely tied to the existence of a space station or some other manned earth orbital activity.

Two representative logistics systems are illustrated in Figure 4 and 5. The first is essentially a state-of-the-art ballistic type reentry vehicle which would be launched on a conventional expendable booster (TIII or new lost cost booster). Some payload volume in the passenger compartment is available for delivery and return of telescope subsystems and experiments. A logistic system of this type is generally expensive to operate but has a relatively low development cost. An advanced logistics system, completely reusable except for propellant tanks, is depicted in Figure 5. This would have a low cost per flight but would be more expensive to develop. A feature of this system would be a capability to launch and recover an entire satellite.

It is also possible that satellite servicing in general will be a major earth orbital activity. This situation may justify development of a reusable space tug which operates from a space station. The tug would retrieve and reposition satellites after servicing or it could even be a manned spacecraft which repairs satellites in situ.

Potential Servicing Modes

Several options are available for servicing as outlined below:

a) servicing from an earth base

    1) in situ

    2) return telescope to earth

b) servicing from a space base (space station)

1) in situ

2) return telescope to space station

There are a number of key technical questions associated with each of these modes affecting mode feasibility and hardware requirements.

For in situ modes it is necessary to establish what level of servicing activity is practical and how much time is required. Involved in the practicality question are the capabilities of EVA and IVA operations, checkout and repair equipment requirements, and the spares which must be carried. Servicing time would establish life support requirements in a space suit or service vehicle.

For return modes it is essential to determine why servicing operations would require return to a service base. It should be established if return is feasible. What are the payload and volume limitations of the logistics vehicle? Can a telescope withstand earth entry conditions within a logistics vehicle? Are there any problems in retracting deployed elements, etc?

The impact on space station design for space station modes must also be determined. For example, what size hangar is required to service telescopes and other satellites? What are the crew requirements? How far away is a telescope? (Involved in this question are station and service vehicle propellant tankage size and communication requirements.)

Programmatic Issues

Technical questions introduce cost uncertainties because of hardware and mode selection uncertainties. However, even if it were possible at this time to select a service mode with well defined hardware it would still be difficult to determine servicing cost. This is because of numerous programmatic issues which affect the cost methodology used.

Of major importance is the concurrent manned space program since a servicing capability is tied to the available hardware and the launch, communications, and crew training facilities. Lack of any manned program would mean that satellite servicing would have to incur major portions of servicing hardware R&D and facilities costs. Occasional minor servicing of a telescope in orbit nearby a space station would probably not add much additional cost to the space station program cost whereas the same servicing operations conducted without a space station may be prohibitively expensive. Alternately, one might ask if the ongoing program is sufficient to support servicing activities or must additional special logistics vehicles and facilities be constructed? (i.e., What is the servicing frequency? Are there any other servicing requirements?)

Another issue affecting cost is the projected uses of the space station and logistics vehicle. Is telescope and other satellite servicing a major use or is servicing considered a minor "slack time" job? If the former situation holds, the corresponding scientific programs should bear part of the station and logistics vehicle R&D and facilities overhead.

What happens during periods when no space station operations are in progress? Must telescope servicing then incur the costs of maintaining manned logistics systems and facilities?

Also to be established is whether a servicing flight tends other satellites also? (i.e., How are flight costs apportioned?)

In summary, many assumptions are necessary to meaningfully establish the costs of servicing any satellite.

<u>Astronomy Program Cost Elements</u>

The total cost of an astronomy program which includes servicing is comprised of the following elements.

1. Telescope Investment

This cost element encompasses first unit telescope cost (which includes R&D), launch cost, ground (or space station) communications, data handling and any other facilities which are specifically constructed for the telescope mission. Telescope cost would vary with the modifications necessary for different levels of servicing (i.e., recall the discussion of Figure 3). Also variable are communications, data handling, and other facilities since these are a function of the desired mode of telescope operation.

2. Servicing Hardware

Some fraction of space station and logistics vehicle R&D should be allocated to astronomy. (Only logistics vehicle R&D applies when servicing is accomplished directly from an earth base rather than a space station.) In addition, modifications to a space station or logistics vehicle for servicing purposes as well as development of a special space tug would be costs directly chargeable to astronomy and other satellite programs requiring servicing.

3. Operation Costs

These costs include telescope mission operations (tracking and data acquisition, experiment planning and preparation,...) and some fraction of SSA and MSF overhead of NASA.* To this must be added some fraction of the space station operating costs (logistics hardware, launch costs, tracking and data acquisition, mission control, mission planning, crew training, spares,...) if the telescope is serviced from the station. Or, if the telescope is serviced from earth, the cost per servicing flight would apply. This latter cost includes items similar to station operation cost items.

<u>Astronomy Program Cost Models</u>

Cost models for a servicing situation with and without a space station are presented in Figures 6 and 7. Both models include the preceeding cost elements and separate development and operational costs. Observe that the R&D, overhead, and program cost elements in these models are multiplied by weighting factors or "astronomy fractions." This fraction is a function of the importance of servicing relative to other station and logistics vehicle uses or it can be representative of the astronomy portion of the total resources expended.

Consider the no space station model for example. In this case the logistics vehicle may have no other use other than servicing satellites. If so, the astronomy fraction of vehicle R&D would be the value of astronomy satellites divided by the value of all satellites that are serviced (perhaps about 1/2). Alternately this fraction could be the number of astronomy servicing flights over the total number of servicing flights.

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*To be consistent, hardware R&D would include all associated SSA and MSF overhead.

The space station model is even more variable for it involves assessments of the relative values of station uses. If the station is intended solely for scientific purposes and satellite servicing the fraction would be the value of astronomy over the value fo space station science and all serviceable satellites. Station science could very well approximate the value of all servicable satellites. Then if astronomy is one half of the value of all satellites, it follows that the astronomy fraction would be about 1/4. More likely the space station and logistics vehicle are good things in themselves, irrespective of scientific uses, since they support future manned space flight goals. For this case the astronomy fraction is quite low (perhaps 1/10), since the denominator then includes the value of the space station and logistics vehicle in addition to station science and all serviceable satellites.

Clearly the astronomy fraction is an intangible and subject to much controversy. It introduces a major cost uncertainty. Other uncertainties also prevent any meaningful servicing cost estimates. At this time, station and logistics vehicle R&D as well as station program cost per year are undefined. R&D costs vary with system size and complexity and yearly program costs are a function of how a program is operated.

An illustration of the effect of launch operations is provided by Figure 8 which presents SIB booster cost as a function of SIB and SV launch rate.* More frequent launches or a large ongoing program (represented by SV launches) are seen to markedly reduce the cost per launch of the SIB. The trend of reducing cost per launch applies to other boosters also. Thus the cost of a servicing flight cannot be established until the base program is established. But it can be noted that a space station program with frequent logistics flights leads to much lower costs per flight than would be the case for occasional servicing flights without any ongoing space station operations.

Cumulative astronomy program costs, based on the example cost models, may exhibit general trends somewhat similar to those indicated in Figure 9. The ordinate starts at the initial telescope investment. Added to this are the servicing hardware costs**--R&D times the astronomy fraction plus special servicing hardware. Noteworthy is the high added cost for the no space station case with an advanced logistics vehicle due to the probable high fraction (of the high development cost)

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*"National Space Booster Study," NASW-1870, Chrysler Corporation Space Division, Saturn Systems Presentation, October 3, 1968.

**Item 2, page 8.

chargeable to astronomy. Use of an existing logistics vehicle would incur little or no added cost but operational costs (represented by the curve slope) would be much higher.

Additional cost for a space station with multiple uses and benefit to manned space flight would be much lower. Even with high station and logistics vehicle R&D, the portion charged to astronomy is relatively low. Operational costs also exhibit a similar trend with a low astronomy weighting factor. The space station mode of operation, although indicated to be much cheaper than other modes, could appear unfavorably with different system S&D costs and allocations to astronomy.

Before any choice of servicing mode can be made it would also be necessary to consider the possibility of replacing telescopes periodically. This is also illustrated.

Summary

In summary, it is not possible to estimate the cost of servicing an astronomy satellite at this time. It is necessary to establish:

- existing NASA programs during time frame that servicing is desired,
- logistics systems that will be available and their operating costs,
- servicing requirements of astronomy and other satellites,
- feasibility and versatility of different servicing modes, and
- a realistic costing methodology.

Acknowledgement

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D. Macchia

1013-DM-nma D. Macchia

Attachments

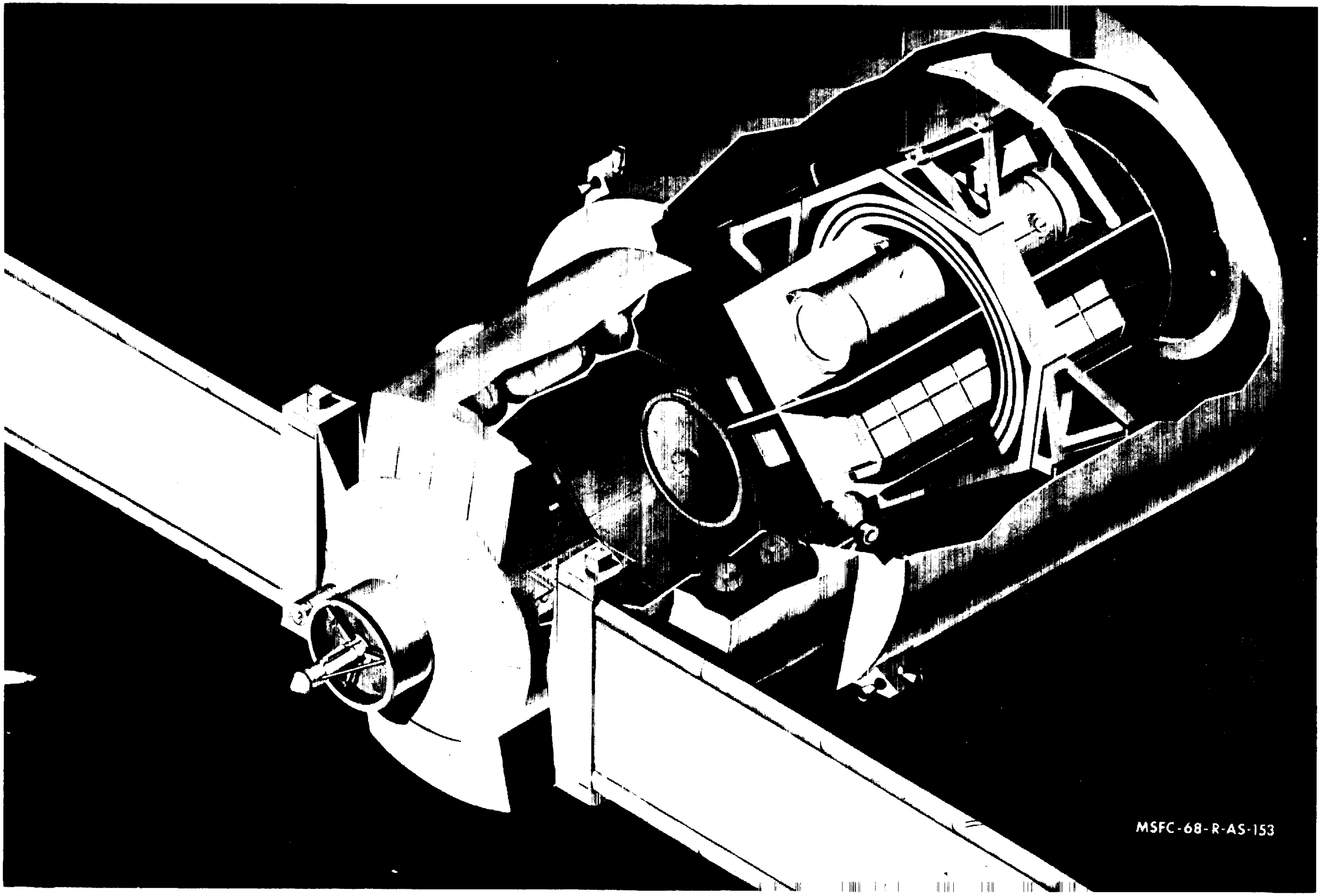

FIGURE 1

MAINTENANCE ANALYSIS RESULTS

CONFIGURATION / SUBSYSTEM/EXPERIMENT	SOLAR		STELLAR	
	FAILURE PER MISSION	MAINT TIME PER MISSION	FAILURE PER MISSION	MAINT TIME PER MISSION
EXPERIMENTS				
PHOTOHELIOGRAPH	1.00	39.0		
H - α TELESCOPE	.47	17.8		
UV LONG WAVE SPEC-TROMETER	.70	26.7		
X-RAY SPECTROHELIO-GRAPH	1.12	49.1		
MAST			1.59	58.6
SUBSYSTEMS				
ON-BOARD CHECKOUT	.01	.8	.01	.8
ELECTRICAL	.05	2.8	.89	45.5
POINTING AND CONTROL	.25	17.2	3.98	218.4
INSTRUMENTATION	3.07	105.9	3.95	155.1
THERMAL CONTROL	.48	23.8	.28	13.5
ATMOSPHERE CONTROL	.06	2.5	.01	.1
PROPULSION			.01	1.0
STRUCTURES	.15	6.4	.03	1.5
TOTALS	7.36	292.0 min	10.75	494.5 min
MEAN TIME TO REPAIR (min)	39.7		46.0	

FIGURE 2

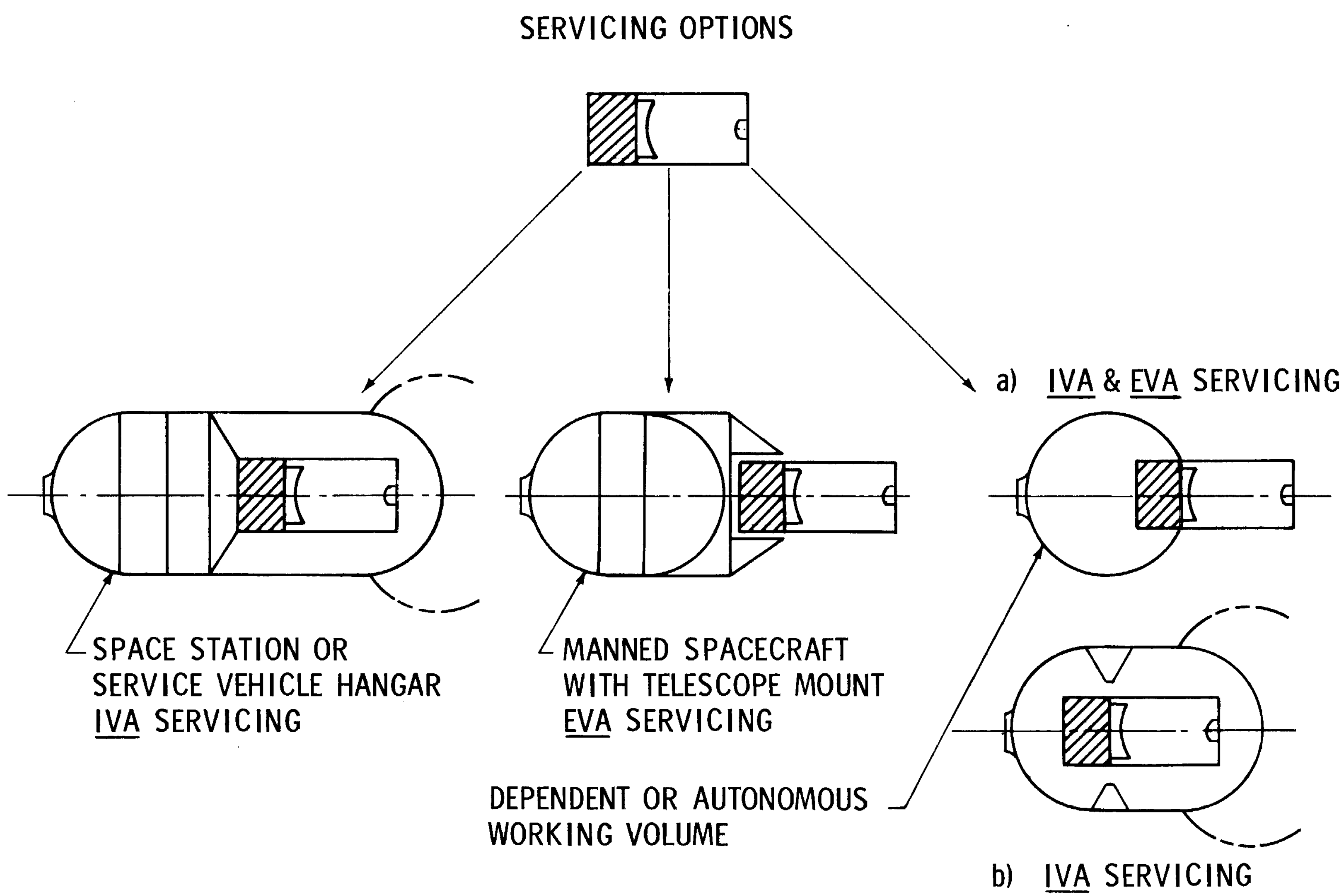
SERVICING OPTIONS
SPACE STATION OR
SERVICE VEHICLE HANGAR
IVA SERVICING
MANNED SPACECRAFT
WITH TELESCOPE MOUNT
EVA SERVICING
a) IVA & EVA SERVICING
DEPENDENT OR AUTONOMOUS
WORKING VOLUME
b) IVA SERVICING

FIGURE 3

MCDONNELL DOUGLAS BIG "G"

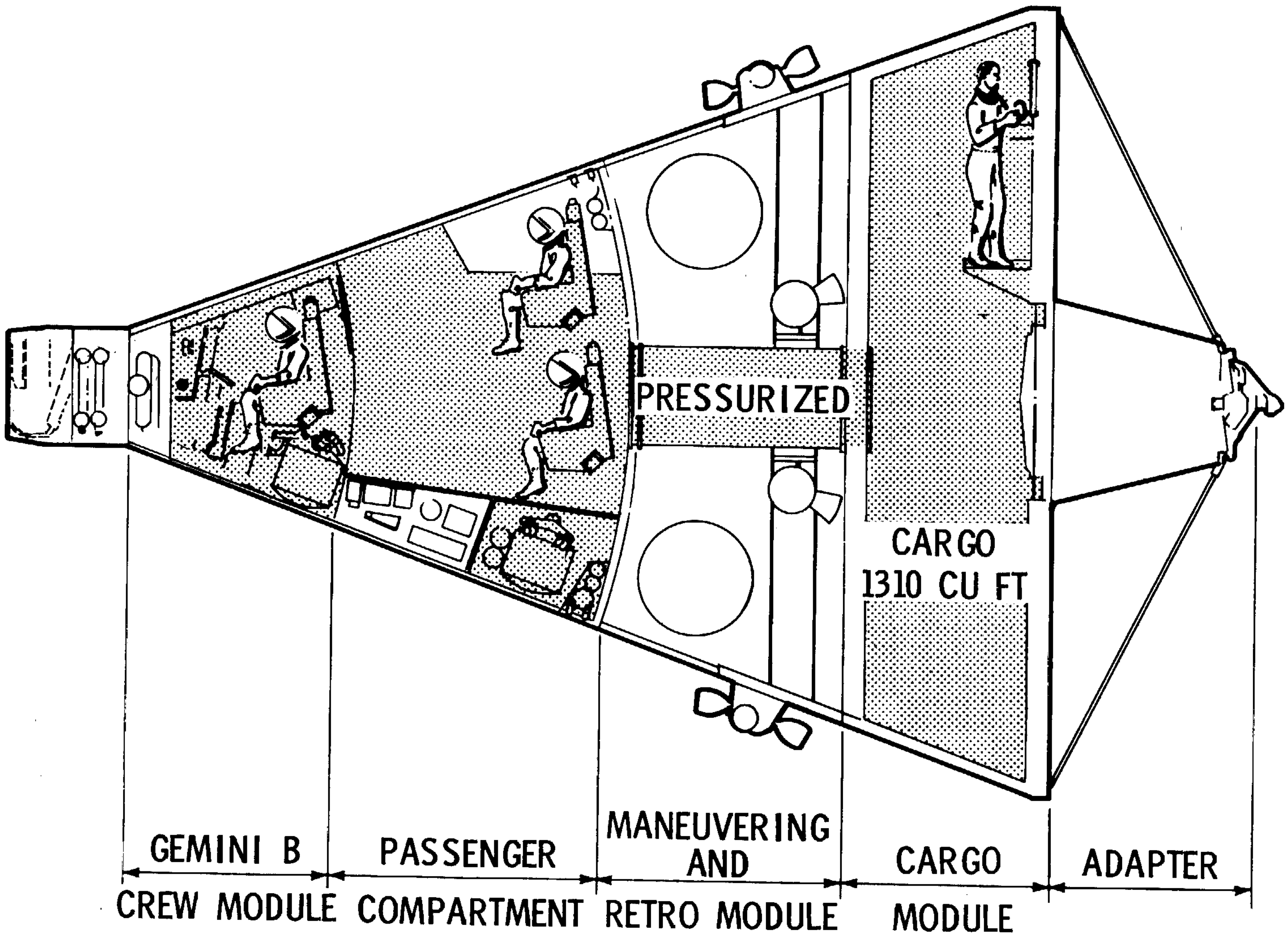

FIGURE 4

1-1/2 STAGE REUSABLE BOOSTER & SPACECRAFT
(LOCKHEED)

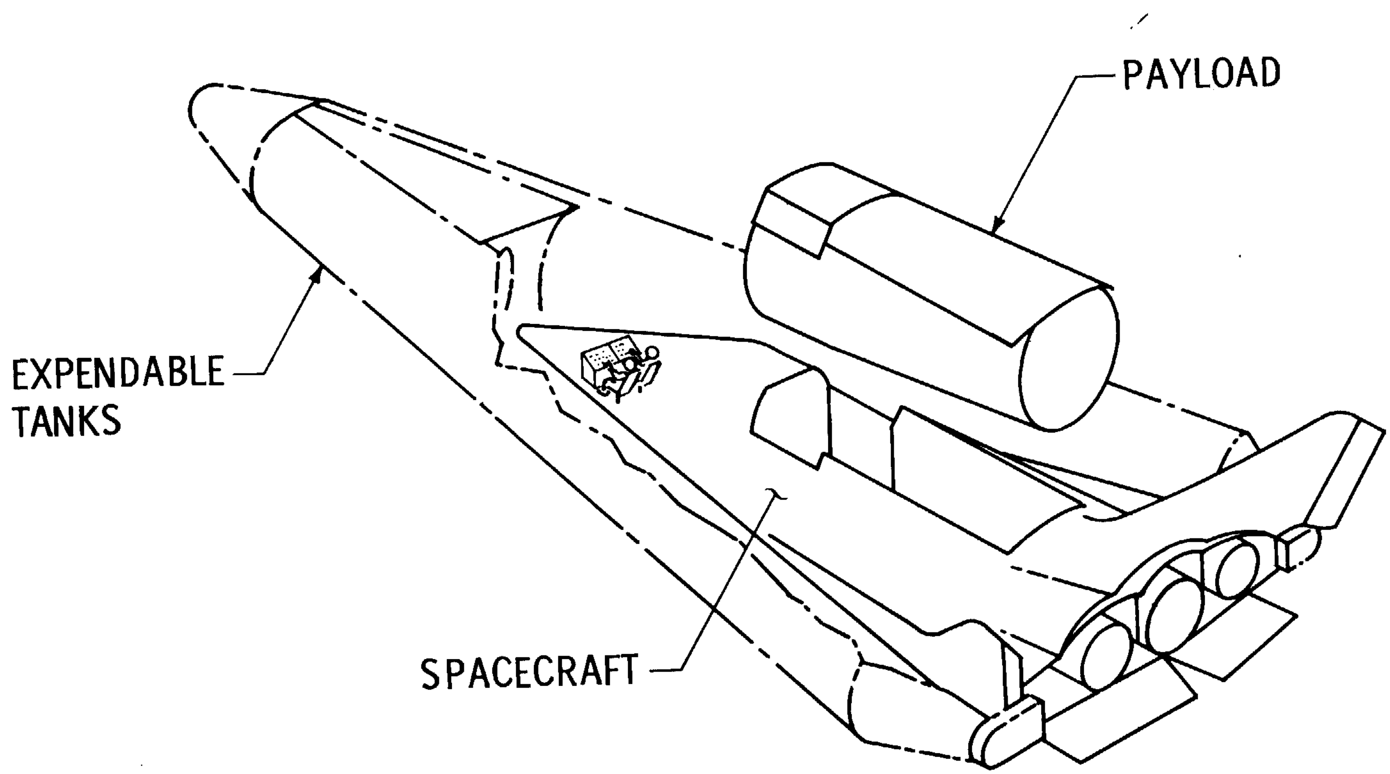

FIGURE 5

COST MODEL - WITH SPACE STATION

DEVELOPMENT COSTS:

$$\left[\text{(LOG. VEH. R\&D + S.S. R\&D)} \times \frac{\text{ASTRONOMY SAT.}}{\text{SPACE STATION** + ALL SAT.*}} \right] + \left[\text{TELESCOPE INVESTMENT} \right]$$

OPERATIONAL COST:

$$\left[\text{SSA AND MSF OVERHEAD} \times \frac{\text{ASTRONOMY}}{\text{MAN PROG. + UNMANNED PROG.}} \right]$$

$$+ \left[\text{S.S. PROGRAM COST PER YEAR} \times \frac{\text{ASTRONOMY SAT.}}{\text{SPACE STATION** + ALL SAT.*}} \right] + \left[\text{TELESCOPE MISSION OPERATIONS} \right]$$

OR

$$\left[\cdots \right] + \left[\text{TELESCOPE MISSION OPERATIONS} \right] + \left[\text{NO. OF LAUNCHES} \times \text{COST PER FLIGHT} \right]$$

*ALL SATELLITES THAT ARE SERVICED

**INCLUDES SPACE STATION SCIENCE & LOGISTICS VEHICLE

FIGURE 6

COST MODEL - NO SPACE STATION

DEVELOPMENT COSTS:

$$\left[\text{LOG. VEH. R\&D} \times \frac{\text{ASTRONOMY SAT.}}{\text{ALL SATELLITES*}} \right] + \left[\text{TELESCOPE INVESTMENT} \right]$$

OPERATIONAL COSTS:

$$\left[\text{SSA AND MSF OVERHEAD} \times \frac{\text{ASTRONOMY}}{\text{MAN PROG. + UNMANNED PROG.}} \right]$$

$$+ \left[\text{NO. OF LAUNCHES} \times \text{COST PER FLIGHT} \right]$$

$$+ \left[\text{TELESCOPE MISSION OPERATIONS} \right]$$

*ALL SATELLITES THAT ARE SERVICED

FIGURE 7

AREA OF EFFORT	RATE (IB/V PER YR)			
	2/0 (MILLION $)	4/0 (MILLION $)	2/2 (MILLION $)	4/4 (MILLION $)
CEI: IU (WITH PLATFORM)	9.346	8.275	8.275	7.296
J-2 ENGINE	2.059	2.059	2.059	1.720
S-IVB	25.856	18.488	17.468	14.206
H-1 ENGINE	2.945	2.145	2.945	2.145
S-IB	12.854	9.164	12.854	9.164
CEI SUPPORT: ENGINES	5.173	4.123	5.173	2.973
CEI SUPPORT: STAGES	8.283	5.267	4.605	3.104
LAUNCH	19.393	11.863	15.808	9.381
LAUNCH SUPPORT	25.840	15.079	23.799	14.290
INTEGRATION	4.646	3.049	4.646	3.049
TOTAL	116.395	79.512	97.632	67.328

FIGURE 8

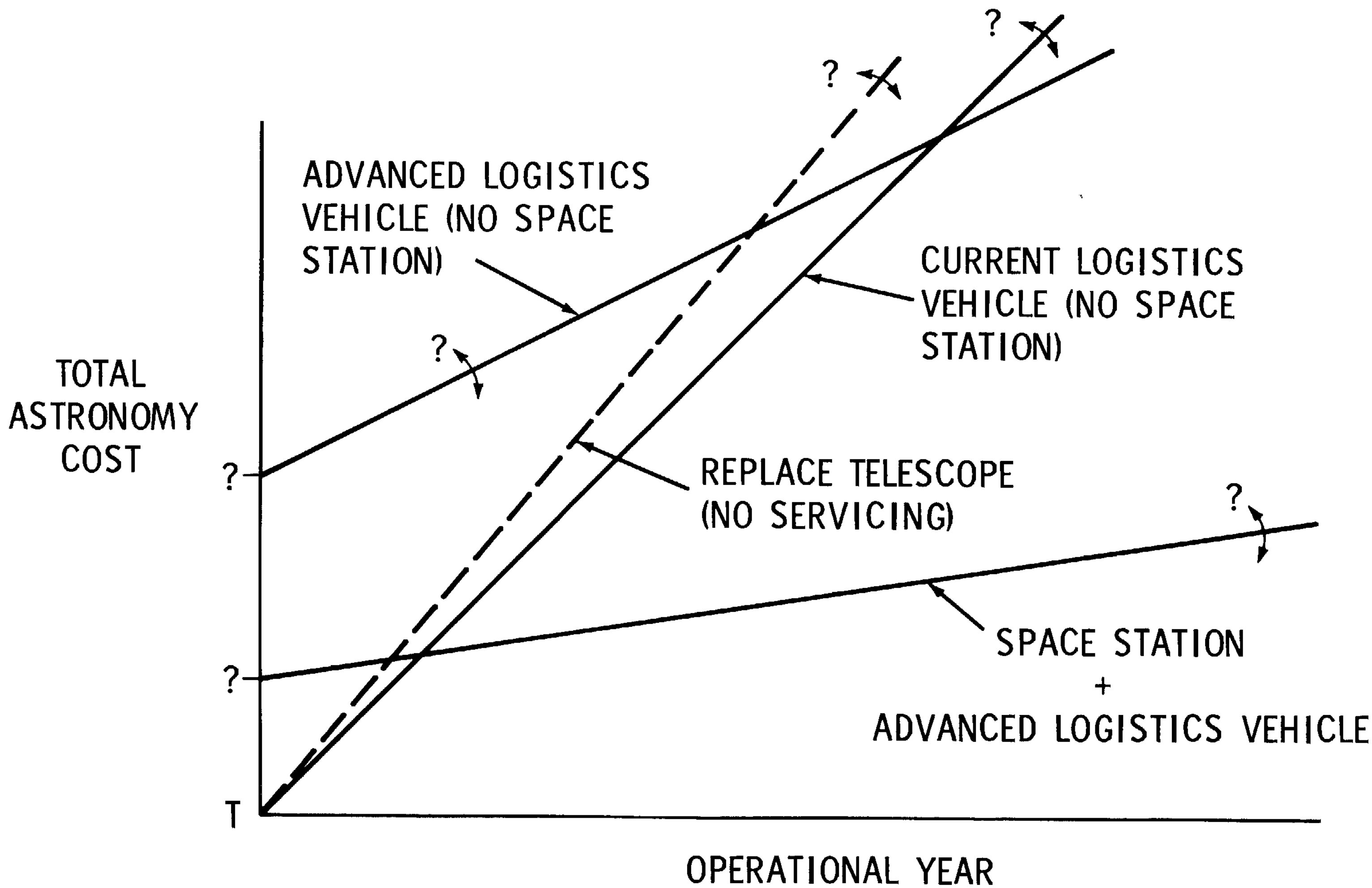
TOTAL
ASTRONOMY
COST
?
?
T
ADVANCED LOGISTICS
VEHICLE (NO SPACE
STATION)
?
?
?
CURRENT LOGISTICS
VEHICLE (NO SPACE
STATION)
REPLACE TELESCOPE
(NO SERVICING)
?
SPACE STATION
+
ADVANCED LOGISTICS VEHICLE
OPERATIONAL YEAR

FIGURE 9

BELLCOMM, INC.

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From: D. Macchia

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